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AUTOMATIC SEARCH JAMMER
(BEAGLE)

Airborne Instruments Laboratory OEMsr-1305

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INTRODUCTION

During the early part of 1944, the Airborne Instruments Laboratory started development work on several automatic search jammers. One of these jammers, known as the BEAGLE, is described in this report. It is a single-frequency jamming transmitter which automatically tunes itself to the frequency of the signal to be jammed. Basically, it consists of a receiver, a control unit, a modulated transmitter, and two servo systems, as indicated in Figure 1.

The receiver servo motor drives the ganged tuning capacitors in the receiver in order to sweep the desired band. When a signal is encountered, the output of the receiver actuates the control unit, which causes the receiver servo motor to tune the receiver accurately to the frequency of the incoming signal. A mechanical brake is then applied to the receiver servo motor shaft. The jamming transmitter is then turned on automatically, and the control unit causes the transmitter servo motor to tune the transmitter to the frequency of the receiver. After a preset transmission time, the cycle of operation is repeated.

This equipment was not developed beyond the experimental model stage. It is the final model which is described in this report.

DESCRIPTION OF FINAL EXPERIMENTAL MODEL

The final experimental model of the automatic search jammer is contained within two cases. In one case are the receiver and transmitter chassis, which are bolted together since one of the tuning capacitors in the transmitter is shaft-driven by the receiver servo motor. The control unit occupies the other case.

RECEIVER - TRANSMITTER

The receiver-transmitter chassis is shown in Figure 2. It is 12 by 25-1/4 by 8-1/2 inches and weighs approximately 33 pounds.

Receiver The 46- to 51-MC receiver is shown schematically in Figure 3. It is conventional except for the incorporation of the motor-driven, ganged, tuning capacitor, and the omission of the audio stages. The receiver consists of the r-f amplifier V101, the local oscillator V102 which is cathode-injected into the frequency converter V103, the 5-MC i-f amplifiers V104 and V105, the 5-MC limiter stage V106, and the 5-MC discriminator stage V107A and B. The two-phase motor M101 drives tuning capacitors C101, C102, and C103 in the r-f stage, the local oscillator, and the converter, respectively. A 400:1 step-down gear ratio is used on the motor. K103 is an electrically operated mechanical brake which is applied to the shaft of M101.

The receiver is adjusted to operate on signals from 100 to 20,000 microvolts in the band from 46 to 51 MC.

Transmitter The circuit schematic for the transmitter is shown in Figure 4. It consists of the audio oscillator V201A and B, the class AB2 modulator V202A and B, and the class C r-f power oscillator V203A and B.

The capacitor C201, driven by the receiver servo motor, provides the rough tuning adjustment for the transmitter. The fine frequency adjustment is made by the trimmer capacitor C203, which is driven by the two-phase motor M201. An 80:1 step-down gear ratio is used on this motor. The trimmer capacitor C202 is used to track condenser C201 with the ganged tuning capacitors in the receiver.

CONTROL UNIT

The control unit chassis is shown in Figure 5. It is 10 by 12 by 7 inches and weighs approximately 11 pounds. Figure 6 is the circuit schematic for this unit. This unit comprises the d-c amplifier V302A and B which derives its input from the rectified output of the discriminator in the receiver; the phasing network Z301; the varistor ring modulator Z302; the 60-cps voltage amplifier V305A; the 60-cps power amplifier V306 which drives the servo motors; the "artificial-signal generator" V304A which supplies the artificial signal necessary to keep the receiver servo motor rotating in one direction in the absence of a signal; the holding circuit V301 and V303A; and the timing circuits V303B, V304B, V305B, V307, and V308A and B.

OPERATION OF FINAL EXPERIMENTAL MODEL

While the receiver is searching the given band (no signal present), the various relays are in the positions indicated in Figures 3, 4, and 6. Relay K104 is the only relay which is energized during the searching operation.

A two-phase induction motor M101 is employed in the receiver servo system. One of the windings is connected permanently to the 115-volt, 60-cps power line and the other winding is connected to the power amplifier V306 (in the control unit) through the output transformer T301. The speed and direction of rotation of the servo motor depend on the magnitude and phase of the variable field voltage.

In the control unit, the d-c amplifier V302A and B and the ring modulator Z302 are each balanced. Since the rectified output voltage of the receiver discriminator is zero in the absence of a signal, no 60-cps power would appear at the variable field winding of the servo motor if it were not for the artificial-signal generator. The artificial-signal generator tube V304A, which is normally conducting, has its plate tied to the plate of V302A. The ring modulator Z302 is thereby unbalanced and an artificial 60-cps signal is introduced in the variable field winding. This causes the motor to rotate rapidly in a direction arbitrarily called positive. In operation, the receiver servo motor continuously drives the ganged capacitors C101, C102, and C103 in the receiver, sweeping the receiver over its search band. However, the band is swept only in the direction of decreasing frequency; that is, from 51 to 46 MC, and not from 46 to 51 MC. This is necessary (as will be explained later) and is accomplished by means of the shorting stator mounted around the ganged capacitor shaft. The stator consists of 180° of conductor and 180° of insulation. Its orientation and the connections are such that the self-biasing grid leak of the limiter V106 is shorted while the band is swept from 46 to 51 MC. Since the voltage developed here is used to indicate to the control unit the presence of a signal, grounding this point renders the control unit inoperative.

As stated previously, relay K104 in the receiver remains energized during the searching operation. This relay is in the plate circuit of tube V308B and so long as the tube conducts, the relay will remain energized. Tube V308B conducts during the searching operation because of the positive bias imposed on its grid by the circuit involving rectifier V308A. In turn, tube V308A receives its plate voltage through tube V305B. This latter tube which is connected as a rectifier prevents excess current in thyratron V307 during the warm-up interval.

When a signal is encountered, a d-c voltage appears at the output of the discriminator V107A and B. This output is linear between 4.86 and 5.18 MC.

The grid of the switching circuit V301 (in the control unit) is connected to the grid of the limiter V106 (in the receiver). When a signal is received, this grid goes highly negative, biasing V301 to cutoff. The instant V301 stops conducting, the diode V303A discharges the grid capacitor of V304A (C301) to ground potential, and, by virtue of the positive bias on its cathode, V304A is cut off. V302A and B are thus no longer artificially unbalanced and servo action takes place.

Torque is developed by the receiver servo motor as a function of the intermediate frequency. Since the signal is encountered while the band is being swept from 51 to 46 MC, the i.f. is decreasing. Thus there is no change in the direction of rotation of the motor until after the inertia of the motor causes the i.f. to go below 5.0 MC. As soon as the discriminator output changes polarity (that is, when the i.f. becomes less than 5.0 MC), the polarity of the d-c input voltage to the ring modulator reverses. This causes a 180° change in phase in the a-c output of the modulator and the direction of rotation of the servo motor is reversed.

The servo process is continued until the receiver is tuned to the frequency of the signal. The voltage difference across the output of the ring modulator is then zero. The rate circuit consisting of the resistor R301 and the capacitor C302 in the cathode circuit of V302A provides the necessary velocity damping in the servo motor to keep it from hunting.

Up to this time the thyratron timer has been biased beyond the firing point by the positive potential on its cathode due to current from V301 and V303B. As V301 is cut off, the thyratron timer V307 becomes ionized and the potential of the cathode of V307 is raised to approximately 200 volts above ground. The diode V303B prevents this high voltage from appearing on the grid of V304A.

When capacitor C303 is charged up to the breakdown potential of the neon bulb (this takes about 0.5 second, and is the time necessary for the servo system to tune the receiver precisely), a high positive voltage appears on the grid of the delay tube V304B, which is normally in the cutoff state. V304B starts conducting and relay K301 is energized for 10 seconds (the preset time for the positive charge on the grid of V304B to leak off from R305).

When relay K301 is energized, contacts A close and contacts B open. The A contacts, in closing, cause relays K103 and K101 in the receiver to be energized. When relay K103 is energized, a mechanical clamp is applied to the shaft of the receiver servo motor. When relay K101 is energized, contacts A open and contacts B close. The A contacts, in opening, remove resistor R101 between the cathode of V101 and ground, thus decreasing the sensitivity of the receiver. The B contacts of relay K101, in closing, short out resistor R102 and capacitor C104. This increases the a.c. flowing through relays K102 and K201, but the current is still too weak to cause those relays to function. Any further relay action in the receiver awaits the de-energization of relay K104. Relays K103 and K101 are connected in series with limiting resistor R104 and resistor R303. The voltage drop across resistor R303 is sufficient to keep thyratron V307 from reigniting, once extinguished, so long as relay K301 is energized.

The B contacts of relay K301, in opening, remove the 300-volt supply from the plate of V305B and, consequently, from the plate of thyratron V307. The plate voltage is also removed from tube V308A and this tube stops conducting. However, tube V308B continues conducting until capacitor C305 has discharged sufficiently. About one second after the B contacts of relay K301 have opened, the grid voltage of tube V308B has been reduced enough to cut off that tube, thus de-energizing relay K104 in the receiver.

When relay K104 is de-energized, contacts A open and contacts B close. Contacts A, in opening, open the variable field winding circuit of receiver servo motor M101. This prevents any further tuning of the receiver. Contacts B, in closing, short out resistor R103 and capacitor C105. This increases the a.c. flowing through relays K102 and K201 to an amount sufficient to energize them.

Contacts A and contacts B of relay K102 open and close, respectively. This switches the lead from the grid of the limiter V106 from the shorting stator in the receiver to that in the transmitter. Contacts C and contacts D close and open, respectively, thereby switching the power for the variable field winding from receiver servo motor M101 to transmitter servo motor M201.

Contacts A and contacts B of relay K201 open and close, respectively, thereby switching the antenna from the receiver to the transmitter. Contacts C close and power is applied to the primary of the power transformer in the 500-volt power supply. Since plate voltage is now applied to the modulator V202A and B and the r-f power oscillator V203A and B, the transmitter starts functioning.

When a signal is tuned in, the transmitter is approximately tracked to the enemy frequency by capacitor C201 (in the transmitter) which is driven by the receiver servo motor. Since the output of the transmitter is much greater than the strength of the enemy signal, the enemy signal is completely blanked out and the receiver responds to the jamming signal. The transmitter servo motor M201 drives the small trimmer capacitor C203, the tuning process being the same as that for the receiver. Thus, any discrepancy between the enemy and the jamming frequencies is corrected by the transmitter servo action.

The interval of transmission, which lasts about 10 seconds, is terminated and all the relays are restored to their initial positions when capacitor C304 has discharged sufficiently through resistor R305 to cut off V304B and, consequently, de-energize relay K301. Capacitor C306, which is charged to the voltage across resistor R303 during the transmit interval, maintains thyratron V307 at cutoff for a short time after relay K301 is de-energized. A transmission cycle is thus prevented from occurring as the result of limiter response to a transmitter transient. After a short interval, capacitor C306 discharges through resistor R303. As previously mentioned, when searching, and in the absence of a signal, the thyratron is cut off by the voltage across resistor R304. Only a part of this voltage charges capacitor C306 because resistor R303 constitutes only a fraction of voltage divider R302 and R303. Resistor R302 thus prevents delay in firing of the thyratron that might otherwise be caused by capacitor C306.

Following the transmit interval and provided that the signal which initiated this cycle is still present, there will be a renewed cycle; if not, there will be a resumption of sweep tuning.

DISCUSSION

In the final model of the BEAGLE, the maximum length of time required to detect an enemy signal and tune the transmitter to the enemy frequency is 13 seconds. The tuning accuracy is within 3000 cps of the enemy signal frequency (46 to 51 MC) for signal strengths between 100 and 20,000 microvolts.

Tuning errors are the result of several factors. In the BEAGLE described, the local oscillator voltage is injected directly into the cathode of the mixer tube. When the input signal becomes too strong, or when the full transmitter power is on, the local oscillator frequency is shifted an appreciable amount by the change of impedance in the mixer-tube cathode circuit. Since the local oscillator is the frequency reference for receiving and transmitting, any change in its frequency during receiving and transmitting results in an error in matching the transmitter frequency to that of the enemy. To remedy this situation, a buffer stage should be incorporated between the local oscillator and the mixer tube. The remaining error is associated with mechanical construction of the braking system and the variable capacitors. Since the same receiver channel is used for both servo systems, any slight, long-time variation in either the receiver or the transmitter frequency alignment is automatically compensated.

Tuning accuracy may be improved considerably by employing two i-f systems, for example, 5 MC and 465 KC, respectively, and superimposing the discriminator outputs of the two systems to control the servo motor. The 5-MC i.f. would be used to adjust the tuning to within a few kilocycles, whereupon the 465-KC channel would take over and make the precise adjustment. An experimental model incorporating such a system has been built. Its accuracy of tuning was good to within ± 100 cps and there were indications that the accuracy could be further improved by the use of a lower intermediate frequency.

Ultimately, the accuracy of the automatic search jammer depends largely on the construction of the servo mechanism. The lower the static friction, the greater will be the accuracy. Electronic velocity damping of the motors is found to be necessary to prevent hunting.

The low rotational speed of the motor is necessary for successful operation of the servo system. However, the maximum time required to tune in a signal may be greatly reduced by using two motors: a high speed motor for searching and a low speed or servo motor for precise tuning. These two motors would be geared (with different gear ratios) to the same ganged capacitor shaft in the receiver. A model of this system has been built. The searching time was cut to a maximum of two seconds, but the system complicated the control unit considerably.

As stated earlier, the band is not swept in the direction of increasing frequency (from 46 to 51 MC). The reason for this follows. If the receiver were allowed to sweep the band in the direction of increasing frequency, the signal would be encountered while the i.f. was increasing. This would give rise to a negative discriminator output which, in turn, would cause the servo motor to reverse. The motor would continue to rotate in the negative direction until the artificial signal generator started to function again. The motor would then begin rotating in the positive direction. Thus the motor would hunt about an i.f. well below 5.0 MC and the receiver would never tune itself to the enemy signal. This effect does not represent a limitation on this type of automatic jamming equipment. Actually, it would not be too difficult to incorporate an appropriate switching device in the jammer which would allow the band to be swept in both directions.

With a mechanically tuned receiver, it is possible to free any particular region within the search band from jamming. This may be accomplished by applying an additional shorting segment to the shorting stator on the shaft of the tuning capacitors.

The receiver and transmitter can be designed to cover a wide band without any sacrifice in the accuracy of tuning, but the search period will be increased.

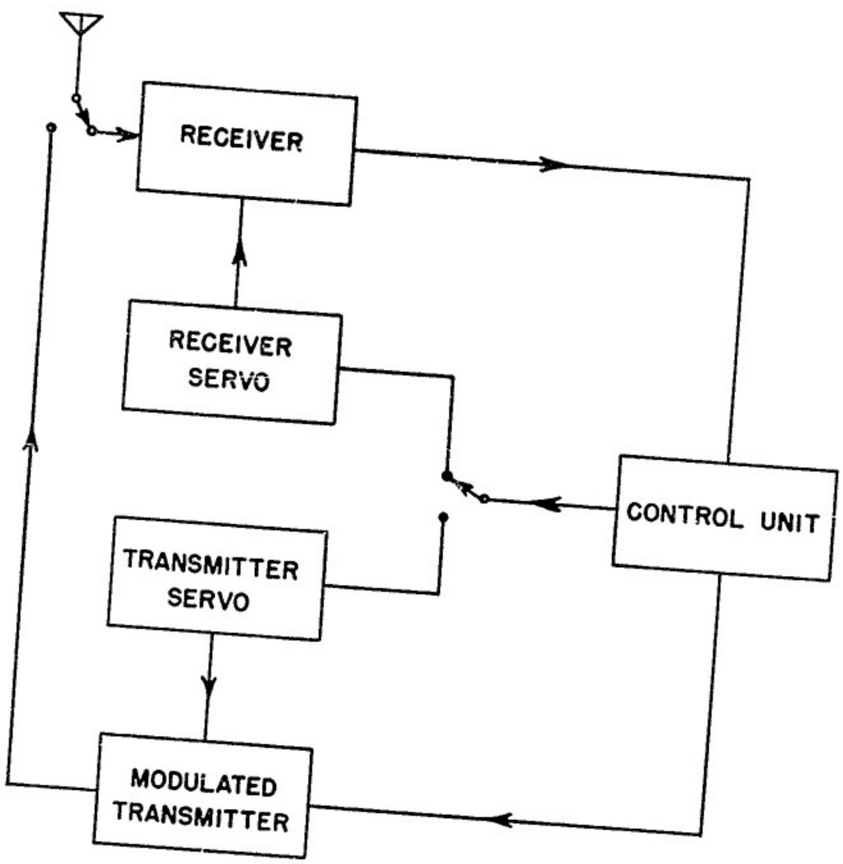

FIGURE 1. BLOCK DIAGRAM OF BEAGLE.

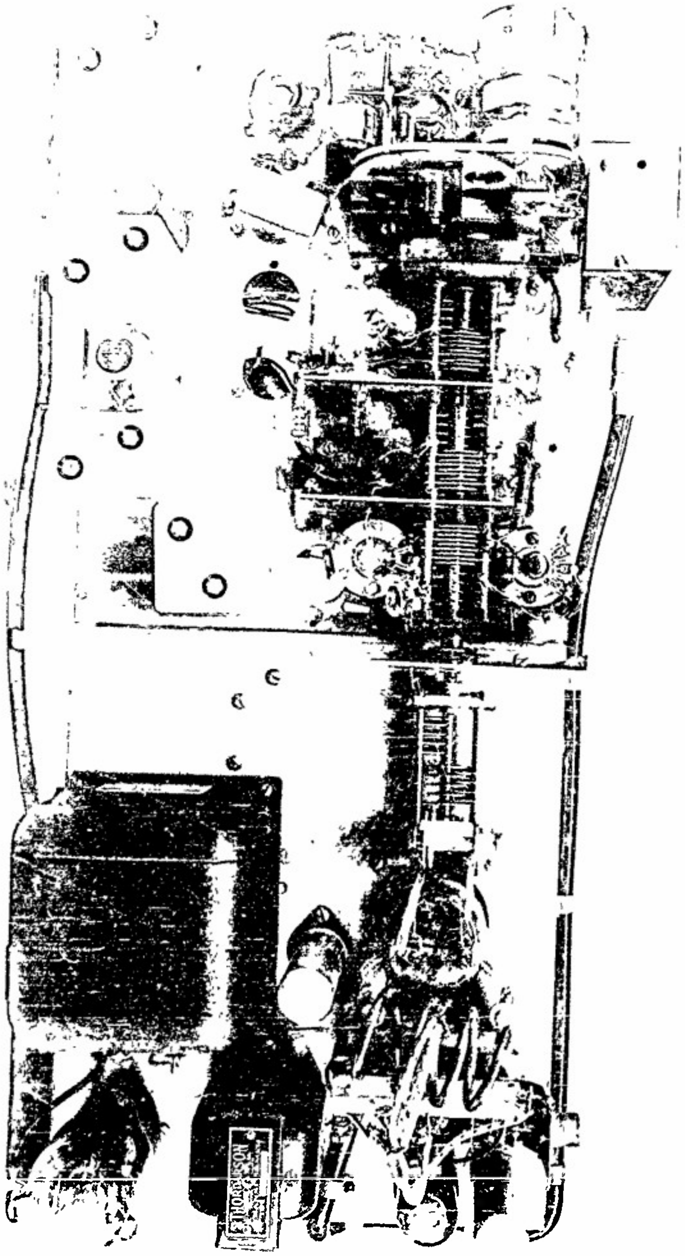

FIGURE 2. RECEIVER-TRANSMITTER CHASSIS.

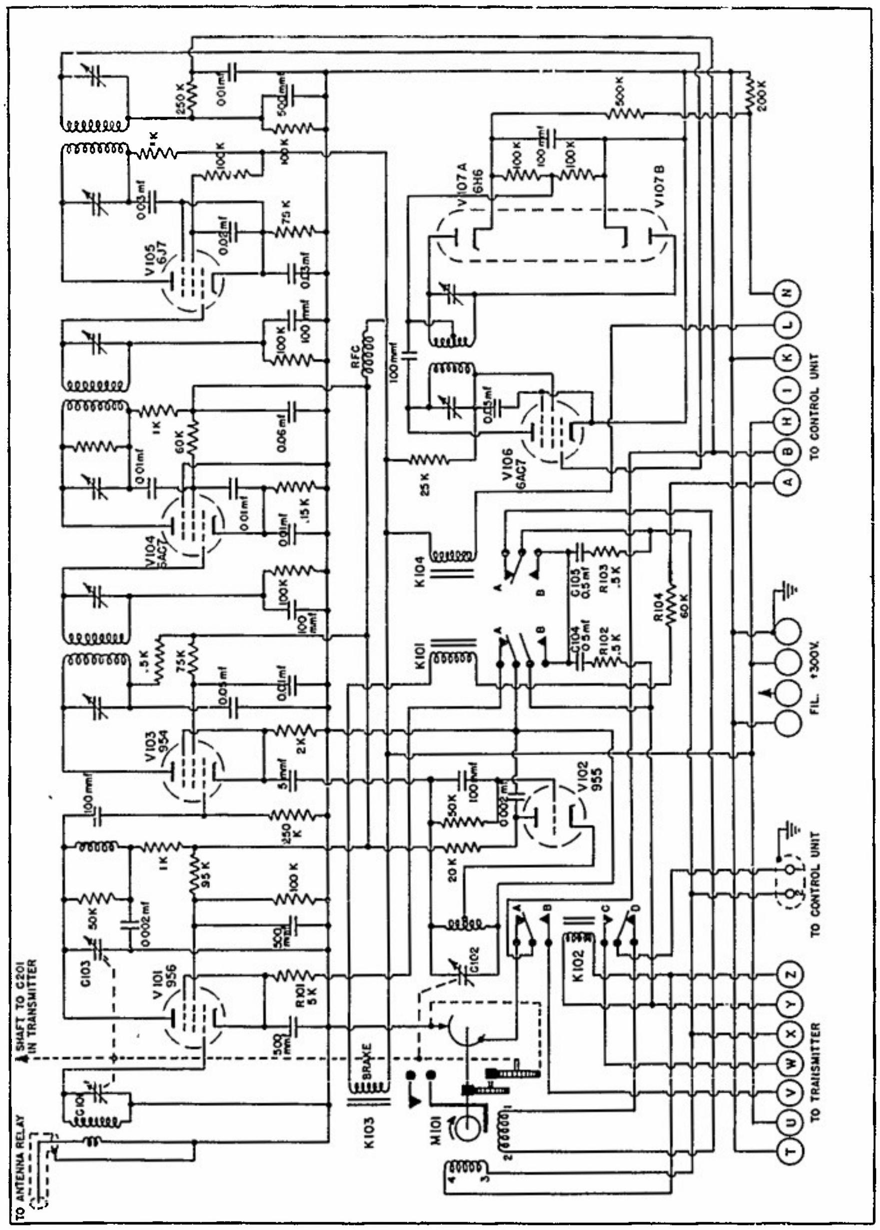

FIGURE 3. SCHEMATIC DIAGRAM OF RECEIVER.

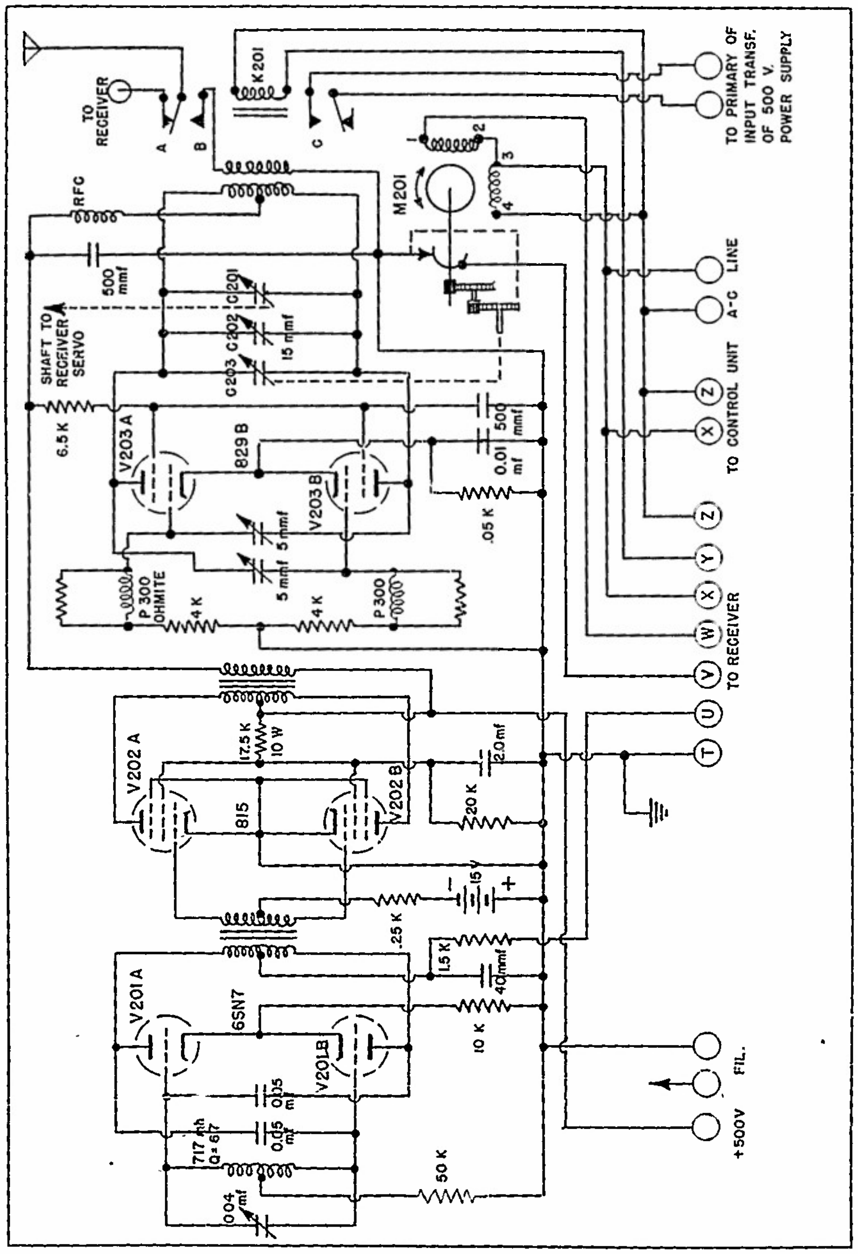

FIGURE 4. SCHEMATIC DIAGRAM OF TRANSMITTER.

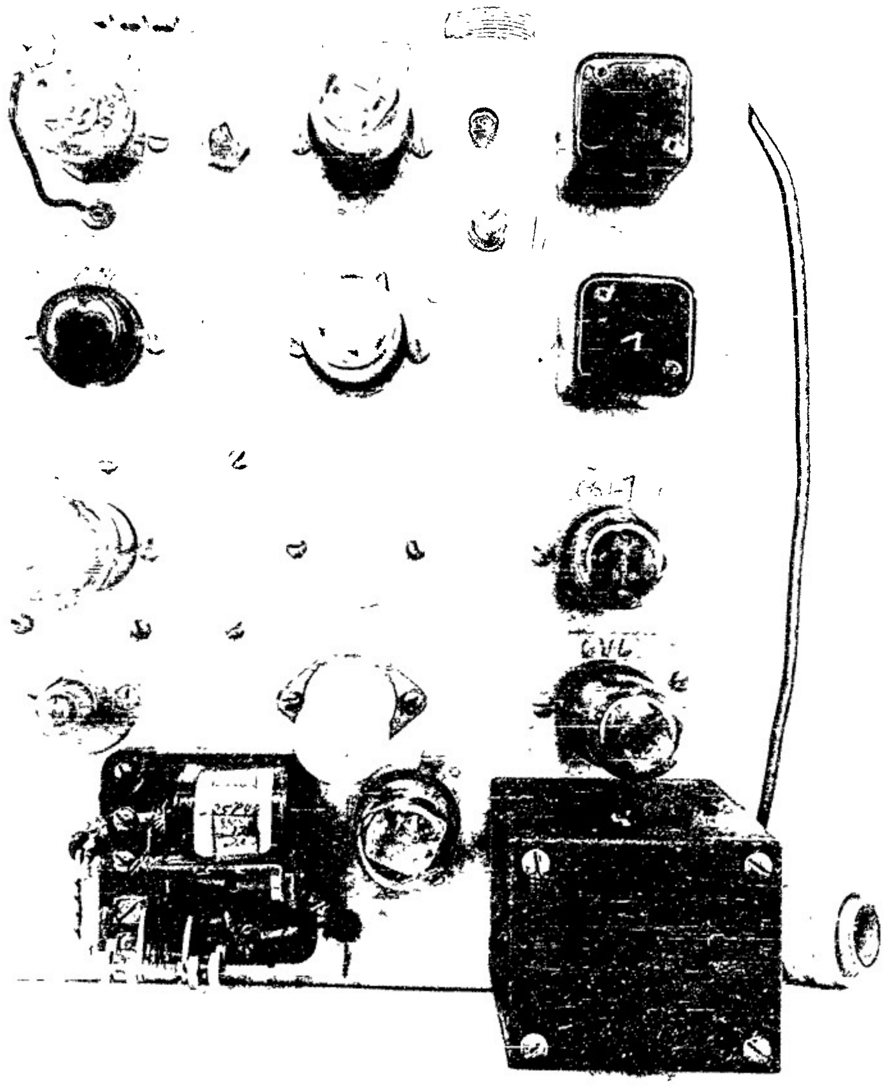

FIGURE 5. CONTROL UNIT CHASSIS.

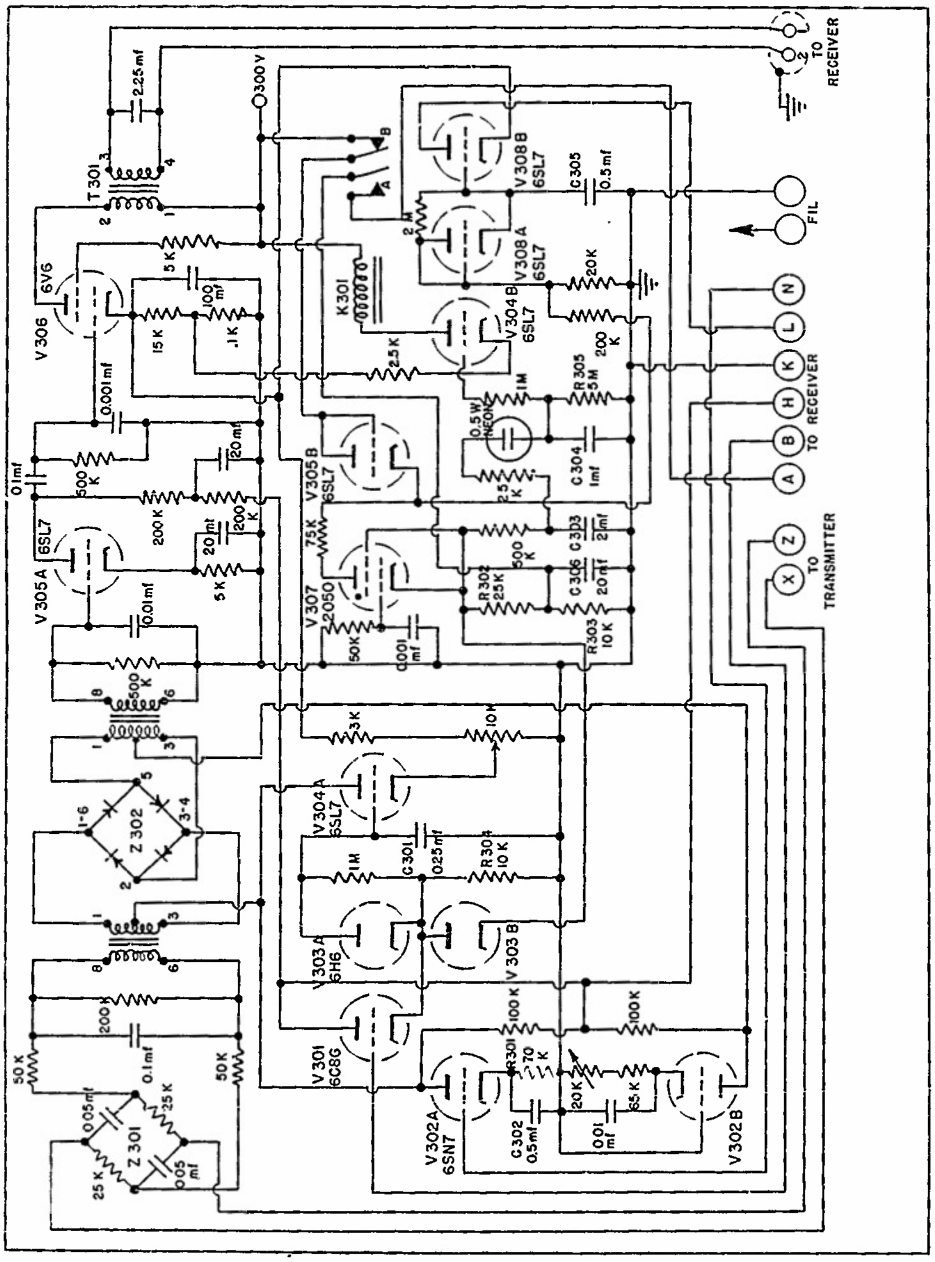

FIGURE 6. SCHEMATIC DIAGRAM OF CONTROL UNIT.

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